

## Template for ISB Documentation of Stressors

### A. General Information: Multiple Stressors - Interactions

1. Name or Location of Example/Approach: meta-analysis of stressor effects on marine and coastal ecosystems
2. Literature/Citations Used: Crain et al. (2008) Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11: 1304-1315. Doi:10.1111/j.1461-0248.2008.01253.x
3. Reviewer(s): Elizabeth Canuel

### B. Specific Questions:

1. What stressors are considered?

Salinity, sedimentation, nutrients, toxins, fishing, sea level rise, temperature, CO<sub>2</sub>, UV, invasives, disease, hypoxia, disturbance.

Interactions between multiple stressors

2. Are stressors categorized? If so, how?

Interactions categorized as additive (26%) synergistic (36%) and antagonistic (38%).

Interaction type varied by response level (community: antagonistic, population: synergistic), trophic level (autotrophs: antagonistic; heterotrophs: synergistic), and specific stressor pair (seven pairs additive; three pairs synergistic; three pairs antagonistic).

3. Are the relations between stressors and management objectives modeled, and if so, how?

4. If stressors are prioritized, describe the general approach.

Variation in multiple stressor effects shows that context matters. In two-thirds of the studies, differences in context changed stressor interaction effect sizes significantly and changed interaction classification to more negative type. For example, number of synergistic interactions doubled in ambient vs, increased levels of third stressor. As number of stressors increased, stressor pair interactions become more complex and more synergistic.

5. How might this approach be relevant to Bay Delta?

Results from this study indicate need to account for stressor interactions in ecological studies and conservation planning. Since multiple stressors impact Delta ecosystem, more likely to be synergistic. Important to consider likelihood of synergistic effects between existing stressors when predicting effects of new stressors such as climate change.

6. Follow up regarding additional questions/literature review/etc?

Conducted Web of Science literature review of papers cited in Crain et al. and papers that have cited Crain et al. (2008).

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### A. General Information: Multiple Stressors - Interactions

1. Name or Location of Example/Approach: experimental simulations
2. Literature/Citations Used: Mora et al. (2007) PROCEEDINGS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES, 274 (1613): 1023-1028
3. Reviewer(s): Elizabeth Canuel

### B. Specific Questions:

1. What stressors are considered? environmental warming, overexploitation and habitat fragmentation
2. Are stressors categorized? If so, how?
3. Are the relations between stressors and management objectives modeled, and if so, how?
4. If stressors are prioritized, describe the general approach.
5. How might this approach be relevant to Bay Delta?

Interaction between habitat fragmentation and harvesting generated an additive decline in population size. However, both of these threats reduced population resistance causing synergistic declines in populations also facing environmental warming. Declines in population size were up to 50 times faster when all threats acted together. These results indicate that species may be facing risks of extinction higher than those anticipated from single threat analyses and suggest that all threats should be mitigated simultaneously, if current biodiversity declines are to be reversed.

Results from this study highlight the importance of generation time in enhancing adaptation to selective forces and in explaining why some species have declined in step with global warming while others have not (e.g. Parmesan & Yohe 2003). These results provide evidence that species with long generation times are more prone to the effects of warming. The overall decline of populations facing any warming also highlights the sensitivity of ecological systems to increases in temperature (Poertner et al. 2001) and suggests that environmental heating itself is capable of causing negative effects on populations independent of other environmental factors that may change in relation to warming (e.g. rainfall, currents, productivity, etc.).

6. Follow up regarding additional questions/literature review/etc?

## Template for ISB Documentation of Stressors

### A. General Information: Multiple Stressors - Interactions

1. Name or Location of Example/Approach: whole ecosystem manipulation experiments
2. Literature/Citations Used: Christensen et al. (2006) Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12, 2316–2322, doi: 10.1111/j.1365-2486.2006.01257.x
3. Reviewer(s): Elizabeth Canuel

### B. Specific Questions:

1. What stressors are considered? interactions between climate and acidification determine their cumulative impact on the food-web structure of coldwater lakes.

2. Are stressors categorized? If so, how?

Interactions among temperature, DOC, and pH were significant predictors of planktonic consumer and producer biomass in Lake 302S. Inclusion of interaction terms increased the predictability of additive models by 20.4% for consumers, and 14.4% for producers.

3. Are the relations between stressors and management objectives modeled, and if so, how?

Results highlight the prevalence and magnitude of interactions among anthropogenic stressors, and that their cumulative impact can generate ecological surprises in lakes. Other studies have similarly demonstrated the complex nonadditive impacts of multiple stressors in marine ecosystems (Hoffman et al., 2003; Przeslawski et al., 2005).

4. If stressors are prioritized, describe the general approach.

5. How might this approach be relevant to Bay Delta?

Interactions among warming, drought, and acidification, rather than the sum of their individual effects, best explained significant changes in planktonic consumer and producer biomass over a 23-year period. These stressors interactively exerted significant synergistic and antagonistic effects on consumers and producers, respectively.

6. Follow up regarding additional questions/literature review/etc? none

## Template for ISB Documentation of Stressors

### A. General Information: Multiple Stressors - Interactions

1. Name or Location of Example/Approach: Field experiment conducted in Antarctica. Authors tested whether 3 phyla of benthic soft-sediment marine invertebrates—annelids, arthropods, and echinoderms—responded differently to two common forms of contamination, organic enrichment and toxic contamination.
2. Literature/Citations Used: Lenihan et al. (2003) Variation in marine benthic community composition allows discrimination of multiple stressors. MEPS 262: 63-73
3. Reviewer(s): Elizabeth Canuel

### B. Specific Questions:

1. What stressors are considered? organic enrichment and toxic contamination
2. Are stressors categorized? If so, how? 3 major benthic phyla, including annelids, respond collectively to separate and interactive effects of organic enrichment and toxicants. Declines in all 3 phyla are probable in sediments with high levels of TOC and/or toxicants because (1) hypoxia/anoxia and toxic hydrogen sulfide are produced in highly enriched sediments (Fenchel & Riedl 1970) and (2) most animals are not able to detoxify or tolerate extremely high levels of many toxicants.

Results from this experiment indicated that annelids (mainly polychaete worms with opportunistic life history strategies from the families Capitellidae, Dorvilleidae, Orbinidae, and Spionidae) respond positively to organic enrichment at all but the highest levels of toxic contamination, and that arthropods and echinoderms respond negatively to toxicants with or without co-occurring organic enrichment.

3. Are the relations between stressors and management objectives modeled, and if so, how?

Efforts to monitor, assess, and protect natural systems from contaminant exposure is beginning to shift from a single-contaminant, single-species emphasis toward identifying how multiple contaminants (or disturbances) influence whole communities at varying spatial scales.

4. If stressors are prioritized, describe the general approach.
5. How might this approach be relevant to Bay Delta?
6. Follow up regarding additional questions/literature review/etc?

## Template for ISB Documentation of Stressors

### A. General Information:

1. Name or Location of Example/Approach: [managing for ocean biodiversity](#)
2. Literature/Citations Used: [Palumbi et al. \(2009\) Managing for ocean biodiversity to sustain marine ecosystem services. Front. Ecol. Environ. 7, doi:10.1890/070135](#)
3. Reviewer(s): [Elizabeth Canuel](#)

### B. Specific Questions:

1. What stressors are considered? General concepts pertinent to multiple stressors
2. Are stressors categorized? If so, how?
3. Are the relations between stressors and management objectives modeled, and if so, how?

[In marine ecosystems, several common ecological mechanisms link biodiversity to ecosystem functioning and to a complex of essential services. As a result, the effects of preserving diversity can be broadly beneficial to a wide spectrum of important ecosystem processes and services, including fisheries, water quality, recreation, and shoreline protection. A management system that conserves diversity will help to accrue more “ecoservice capital” for human use and maintain a hedge against unanticipated ecosystem changes from natural or anthropogenic causes.](#)

4. If stressors are prioritized, describe the general approach.
5. How might this approach be relevant to Bay Delta?

[Management strategies should be structured around broad system properties such as diversity and maintenance of ecosystem services rather than individual species. Diversity enhances a variety of ecological processes. These enhanced processes accelerate benefits that ecosystems provide in terms of recovery, resistance, protection, recycling, recreation, etc](#)

6. Follow up regarding additional questions/literature review/etc?

## Template for ISB Documentation of Stressors

### A. General Information: [Multiple Stressors - Interactions](#)

1. Name or Location of Example/Approach: [Chesapeake Bay](#)

2. Literature/Citations Used:

[Breitburg, D.L. & G.F. Riedel \(2005\) Multiple stressors in Marine Systems. In: The Sciences of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder \(eds.\), Island Press, Washington DC.](#)

3. Reviewer(s): Elizabeth Canuel

### B. Specific Questions:

1. What stressors are considered?

[Nutrient loading and overfishing:](#) when overfishing reduces populations of herbivores or suspension feeders that consume primary producers, it potentially increases deleterious effects of nutrient loading.

- [Overfishing and nutrient enrichment may alter food web – may lead to greater fisheries production initially in oligotrophic systems.](#)

[Trace metals and nutrients:](#) interactions between trace elements and nutrients can alter patterns of spatial and temporal variability within marine systems

- [Trace elements can mask or reduce effects of high nutrient loadings](#)

[Disease and parasites with other stressors:](#) combined effects of overfishing and disease were greater than either alone because together they reduced total community herbivory and eliminated potential for compensatory responses by one set of herbivores as the other declined. Reduction in total herbivory then made community more susceptible to a third stressor – physical disturbance due to storms.

2. Are stressors categorized? If so, how?

[This paper provides conceptual model of unique patterns of stressor effects and the scales of how they impact ecosystems \(e.g., chemical toxicity may be intense at local level but weak on wide scale while effects of global climate change are likely to be widely distributed\).](#)

[Additive/synergistic stressors – the change caused at physiological or ecological by one stressor increases the severity or occurrence of effects of second stressors](#)

Antagonistic (or less than additive) –stressors have overlapping effects or one stressor reduces the effects of other stressors

3. Are the relations between stressors and management objectives modeled, and if so, how?
4. If stressors are prioritized, describe the general approach.
5. How might this approach be relevant to Bay Delta?
  - Individual stressors fundamentally change the playing field upon which additional stressors act by selecting for tolerant species and by changing the abundance, distribution or interactions of structural species, predators, prey, parasites and hosts.
  - Recovery period from a particular stress can extend beyond the period of exposure, influencing the response to subsequent stressors (e.g., this may be the case for legacy sediments and materials associated with these sediments).
  - Effects of stressors can extend beyond spatial scale of stressor, increasing the potential for interactions with additional stressors.
  - Over time, heritable adaptations that increase tolerance to one class of stressors can increase susceptibility to others (Meyer and DiGiulio (2003) Ecol Applic. 13: 490-503).
6. Follow up regarding additional questions/literature review/etc?



## Template for ISB Documentation of Stressors

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#### 1. Name or Location of Example/Approach:

The aim of this work was to test the hypothesis that the effects of multiple stressors on ecosystem processes depend upon the interaction between their respective temporal patterns. The experimental site was a fourth-order stream (Glencree River, County Wicklow, Ireland).

#### 2. Literature/Citations Used:

Molinos, J.G. and I. Donohue (2010) Interactions among temporal patterns determine the effects of multiple stressors. *Ecological Applications*, 20(7), pp. 1794–1800

#### 3. Reviewer(s): Elizabeth Canuel

### B. Specific Questions:

1. What stressors are considered? increased sediment loading and nutrient enrichment

2. Are stressors categorized? If so, how?

3. Are the relations between stressors and management objectives modeled, and if so, how?

This paper reports that interactions among temporal disturbance regimes determined the effects of the compounded sediment and nutrient perturbations on algal biomass and the diversity, taxonomic and trophic composition of benthic assemblages. Results from this study also show that the temporal synchronization of multiple stressors does not necessarily maximize the impact of compounded perturbations.

4. If stressors are prioritized, describe the general approach.

5. How might this approach be relevant to Bay Delta?

This paper provides experimental evidence that interactions among the temporal patterns of disturbances drive the responses of ecosystems to multiple stressors. Knowledge of the temporal pattern of disturbances is therefore essential for the reliable prediction of impacts from, and effective management of, compounded perturbations.

6. Follow up regarding additional questions/literature review/etc?